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Physiological Responses to Swimming Repetitive "Ice Miles"

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Abstract

Knechtle, B, Stjepanovic, M, Knechtle, C, Rosemann, T, Sousa, CV, and Nikolaidis, PT. Physiological responses to swimming repetitive "Ice Miles." *J Strength Cond Res* XX(X): 000–000, 2018—"Ice Mile" swimming (i.e., 1,608 m in water of below 5° C) is becoming increasingly popular. Since the foundation of the International Ice Swimming Association (IISA) in 2009, official races are held as World Cup Races and World Championships. Ice swimming was a demonstration sport at the 2014 Winter Olympics in Sochi, Russia. This case study aimed to identify core body temperature and selected hematological and biochemical parameters before and after repeated "Ice Miles." An experienced ice swimmer completed 6 consecutive Ice Miles within 2 days. Three Ice Miles adhered to the strict criteria for the definition of Ice Miles, whereas the other 3 were very close (i.e., 5.2, 6.1, and 6.6° C) to the temperature limit. Swimming times, changes in core body temperatures, and selected urinary and hematological parameters were recorded. The athlete showed after each Ice Mile a metabolic acidosis (i.e., an increase in lactate and TCO_2; a decrease in base excess and HCO_3^-) and an increase in blood glucose, cortisol, and creatine kinase concentration. The decrease in pH correlated significantly and negatively with the increase in cortisol level, indicating that this intense exercise causes a metabolic stress. The change in core body temperature between start and finish was negatively associated with metabolic acidosis. The increase in creatine kinase suggests skeletal muscle damages due to shivering after an Ice Mile. For athletes and coaches, swimming in cold water during Ice Miles leads to a metabolic acidosis, which the swimmer tries to compensate with a respiratory response. Considering the increasing popularity of ice swimming, the findings have practical value for swimmers and practitioners (e.g., coaches, exercise physiologists, and physicians) working with them because our results provide a detailed description of acute physiological responses to repeated swimming in cold conditions. These findings are of importance for athletes and coaches for National Championships and World Championships in Ice Swimming following the IISA rules.

Key Words cold water, aquatic sports, hypothermia, thermal stress

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Introduction

Ice swimming is a new discipline in open-water swimming of increasing popularity (19). In 2009, the International Ice Swimming Association (IISA) was formed with the vision to formalize swimming in icy water (www.internationaliceswimming.com/). The IISA introduced the 'Ice Mile' as the ultimate achievement of swimming in cold waters. An Ice Mile is defined as swimming 1 mile in water of 5° C or less. Between 2009 and 2015, already 113 men and 38 women had completed 1 Ice Mile (19).

One of the most important problems in swimming in cold water is hypothermia and afterdrop (26). On one hand, hypothermia (i.e., core body temperature <35° C) could lead to tachycardia and increased levels of circulation stress hormones (37,38), which might impair physical performance. Furthermore, the dynamic response of peripheral cold receptors, especially in initial immersion, leads to hyperventilation and the loss of control of breathing can be a precursor to drowning (37,38). On the other hand, the afterdrop, defined as a decrease in core body temperature observed as a complication during rewarming of a hypothermic person, could increase the potential risk of myocardial temperature decline and ventricular fibrillation (32).

Exercise in extreme environments, e.g., swimming in cold water, is a major field of exercise physiology. In this context, the "Ice Mile" could be an example to study acute physiological responses to swimming in cold water. However, so far, limited research has been conducted on this sport (18–20,34). An

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Table 1. Environmental conditions and characteristics of swimming.

No. of mile	Distance (m)*	Water temperature (°C)	Air temperature (°C)	Duration of the "Ice Mile" (min)
1	1,670	6.1	14.5	41
2	1,630	4.7	14.9	41
3	1,710	5.2	15.1	43
4	1,900	4.1	10	42
5	1,690	4.9	4.5	30
6	1,990	6.6	11	44

*Because of the blowing of a strong wind, the swimmer was not able to swim directly in-line between the buoys. This resulted in different covered distances in each mile and this was the reason we measured distance of each mile with his own GPS-watch.

analysis of "Ice Miles" held between 2009 and 2015 showed that men were faster than women, and swimming speed was not correlated with water temperature (19). The first study conducted ever in this discipline examined the case of an athlete whose core body temperature decreased by 1.7° C while swimming and by 3.2–3.7° C after the swim to reach the lowest temperature ~100 minutes after the start (20). The second study was conducted on 2 swimmers who experienced afterdrops of −3.6 and −2.4° C, reaching the lowest points 38 and 23 minutes after the swim, respectively (18). In addition to the 2 above-mentioned studies that examined single races (18,19), a case study of a swimmer completing 3 consecutive Ice Miles showed metabolic acidosis in the first and the third race, which the swimmer compensated with hyperventilation (i.e., leading to respiratory alkalosis) (34). Thus, the investigation of repeated Ice Miles might provide additional information about the acute physiological responses to prolonged swimming in cold water.

Therefore, physiological changes reported during and after swimming an "Ice Mile" would be of great application to exercise physiologists, strength and conditioning coaches, athletes and enthusiasts to plan performance improvement strategies, and to ensure the health of the swimmer during and after an "Ice Mile." In the present case report, we studied changes in core body temperature and selected hematological parameters in an experienced male ice swimmer completing several Ice Miles in a row to quantify the stress. We measured, therefore, the concentration of cortisol and several parameters of acidosis and alkalosis before and after each "Ice Mile." Based on existing research, we hypothesized that cortisol would be increased after an "Ice Mile" and pH would be increased because of alkalosis after hyperventilation.

Methods

Experimental Approach to the Problem

The swimmer swam 6 Ice Miles within 1 weekend; among them, 3 adhered to the strict criteria for the definition of Ice Miles (i.e., water temperature <5° C), whereas the other 3 were very close (i.e., 5.2, 6.1, and 6.6° C) to the temperature limit. A preliminary analysis examined the differences in percentage changes during the 6 swims between these conditions (i.e., water temperature <5 vs. ≥5° C), and because there was no difference, they were considered together for the purpose of this study.

Based on previous experience (34), the swimmer intended to start a next "Ice Mile" about 2–4 hours after finishing the last "Ice Mile." The event took place in the harbur of Nonnenhorn (www.nonnenhorn.eu) at Lake Constance, Germany, starting on Friday evening March 3, 2017. Before and after each "Ice Mile," the swimmer consumed his standard meal consisting of a sandwich and a soft drink. After the first and the fourth "Ice Mile," the athlete slept for about 6 hours. The athlete followed no specific protocol for rewarming between the Ice Miles. After getting out of the water, he walked to the lodging in the harbor of Nonnenhorn. We dried his skin with a towel and he put on his tracksuit. Then, he shivered for a few minutes. After that, he consumed his soft drink and ate his sandwich.

Subjects

The subject was an experienced open-water ultra-swimmer (mean ± *SD* age, 58 years; body mass, 106.7 kg; body height, 1.76 m; and body mass index, 34.4 $kg \cdot m^{-2}$). He was the first swimmer ever to cross the Fehmarn-Belt, from Fehmarn (Germany) to Rødby (Denmark) and back to Fehmarn (i.e., double crossing, 2 × 25 km, 16° C water temperature) in 2011. In 2012, he completed a 6-hour swim in water colder than 10° C (29). In 2015, he swam 2 Ice Miles on 2 different days (20). In 2016, he completed 3 consecutive Ice Miles within 15 hours (34). The subject was without any previously diagnosed medical conditions, was not taking any medication, and no history of nonfreezing cold injury such as loss of sensation, skin damage/infection, or nerve damage (20).

The experiment was approved by the Ethics Committee of the Kanton St. Gallen, Switzerland, and the subject provided his written informed consent for data collection and publication of the data.

Procedures

Body composition was measured using "BC-568 Segmental Body Composition Analyser" (Tanita, Tokyo, Japan) to determine body fat percentage, lean body mass, visceral fat mass, bone mass, and body weight. The analyzer measures weight with increments of 0.1 kg and body fat increments with 0.1%. During all Ice Miles, the athlete wore his

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Table 2. Biochemical values before and after an "Ice Mile."

	1 h before swim	Preswim	Postswim	30 min after swim	Δ post-pre	*p*	η^2
pH	7.44 ± 0.02	7.45 ± 0.03	7.35 ± 0.05	7.40 ± 0.03	−0.10 ± 0.07	0.002	0.620
pCO_2 (kPa)	4.58 ± 0.20	4.63 ± 0.36	4.57 ± 0.37	4.66 ± 0.33	−0.06 ± 0.55	0.942	0.015
pO_2 (kPa)	8.94 ± 0.86	9.02 ± 1.26	10.02 ± 1.42	8.47 ± 1.26	1.00 ± 0.66	0.233	0.253
Base excess (mmol·L^{-1})	−0.83 ± 1.60	0 ± 1.26*	−6.50 ± 2.88	−3.17 ± 1.17†	−6.50 ± 3.94	0.010	0.703
HCO_3 (mmol·L^{-1})	23.38 ± 1.28	23.98 ± 1.28	19.05 ± 2.55	21.80 ± 1.00	−4.93 ± 3.57	0.021	0.630
Total CO_2 (mmol·L^{-1})	24.33 ± 1.37	25.17 ± 1.72	20.17 ± 2.64	22.67 ± 1.03	−5.00 ± 4.10	0.029	0.583
O_2 saturation (%)	93.17 ± 1.47	94.00 ± 1.67	94.00 ± 1.67	91.17 ± 3.19	0 ± 0.63	0.193	0.287
Lactate (mmol·L^{-1})	1.28 ± 0.48‡	1.67 ± 0.58	5.75 ± 2.29§	2.28 ± 0.30	4.08 ± 2.70	0.009	0.754
Sodium (mmol·L^{-1})	140.17 ± 1.72	140.50 ± 1.05	141.50 ± 1.05	139.33 ± 1.86	1.00 ± 1.41	0.205	0.277
Potassium (mmol·L^{-1})	4.68 ± 1.05	4.33 ± 0.39	4.93 ± 0.44	4.85 ± 0.98	0.60 ± 0.49	0.402	0.160
Chloride (mmol·L^{-1})	108.17 ± 0.41‡	108.17 ± 1.60	110.50 ± 1.38§	108.83 ± 0.75	2.33 ± 1.86	0.009	0.633
Ionized calcium (mmol·L^{-1})	1.19 ± 0.07	1.15 ± 0.04	1.14 ± 0.07	1.11 ± 0.07	−0.01 ± 0.10	0.319	0.203
TCO_2 (mmol·L^{-1})	22.17 ± 0.41‡	22.17 ± 1.60	19.33 ± 1.63§	21.33 ± 1.51	−2.83 ± 2.56	0.033	0.495
Glucose (mmol·L^{-1})	6.02 ± 0.77*‡	10.23 ± 2.61	8.68 ± 0.77§	8.08 ± 0.59§	−1.55 ± 2.00	0.023	0.637
Urea (mmol·L^{-1})	7.10 ± 1.37	7.82 ± 1.22	8.47 ± 2.29	8.33 ± 2.15	0.65 ± 1.40	0.128	0.326
Creatinine (μmol·L^{-1})	50.17 ± 5.31	48.50 ± 2.07	52.50 ± 2.88	47.50 ± 3.27	4.00 ± 3.52	0.115	0.381
Hematocrit (%)	45.17 ± 5.15	46.33 ± 6.62	49.33 ± 4.80	49.50 ± 5.72	3.00 ± 2.61	0.257	0.244
Hemoglobin (g·L^{-1})	154.17 ± 17.57	148.67 ± 9.85	165.00 ± 12.70	160.67 ± 14.38	16.33 ± 7.89	0.179	0.306
Anion gap (mmol·L^{-1})	15.00 ± 0.63	15.67 ± 1.51	17.17 ± 1.94	15.17 ± 0.98	1.50 ± 2.26	0.101	0.368
Creatine kinase (U·L^{-1})	277.17 ± 67.27*‡	279.67 ± 58.19‡	345.33 ± 84.53†§	324.50 ± 67.38§	65.67 ± 34.10	<0.001	0.791
Cortisol (nmol·L^{-1})	266.67 ± 127.00‡	284.67 ± 81.99‡	607.33 ± 160.94*†§	423.83 ± 125.72‡	322.67 ± 151.21	0.002	0.781
Urine pH		5.17 ± 0.41	5.00 ± 0		−0.17 ± 0.41	0.363	0.167
Urine density		1.02 ± 0.00	1.02 ± 0.01		0 ± 0	0.093	0.463
Urine protein		10.00 ± 15.49	10.00 ± 15.49		0 ± 18.97	1.000	0

*Statistical difference from 1 hour before start, prerace, postrace, and 1 hour after finish, respectively.
†Statistical difference from 1 hour before start, prerace, postrace, and 1 hour after finish, respectively.
‡Statistical difference from 1 hour before start, prerace, postrace, and 1 hour after finish, respectively.
§Statistical difference from 1 hour before start, prerace, postrace, and 1 hour after finish, respectively.

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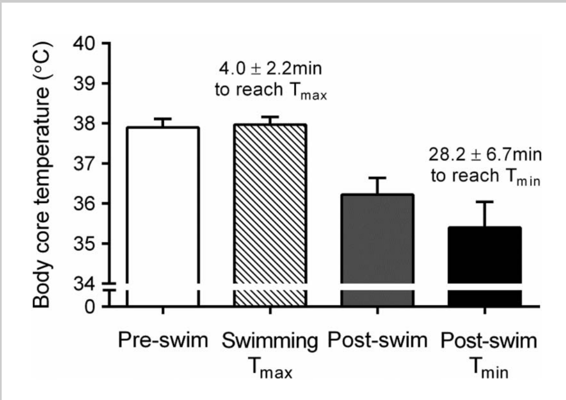

Figure 1. Changes in body temperature during swimming; error bars represent *SD*s.

swimming trunks and swimming goggles. The swimming distance was measured using a global positioning system (GPS) unit (SPOT Gen3 Satellite messenger, www.findmespot.eu/gm), which the swimmer took with him in every "Ice Mile." The swimmer put his GPS watch in his rescue bag, which was attached to his swim pants.

Water temperature was measured continuously 1 m below the surface with 3 different thermometers using thermoelectric probes from Endotherm (EndoTherm GmbH, Arlesheim, Switzerland). The official referee who controlled the record attempt set 3 sensors away from the shore in the lake at different places to measure water temperature continuously. Endotherm measures temperatures from −40° C to +85° C with a resolution of 0.0625° C and a precision of 0.1° C. Before a start, water temperature was also measured using a liquid-crystal display (LCD) hand-operated thermometer DT-300 (Voltcraft, Hirschau, Germany), with a temperature accuracy of 0.1° C.

We determined hematological and urinary parameters before and after each "Ice Mile." Capillary blood samples were taken 1 hour before a start, immediately before the start, immediately after finishing, and based on previous experience at 30 minutes after finish when the lowest core body temperature was expected (34). Based on this first record attempt, we observed that the swimmer was very calm before he started with the preparations but got more and more nervous toward the start, and thus, we decided to obtain 2 measurements. The blood samples were taken from the ear lobe using a capillary blood collection system containing lithium heparin (Kabe Labortechnik GmbH, Nümbrecht, Germany) and analyzed using the i-STAT (Axonlab, Baden, Switzerland) system using CHEM 8+ (i.e., [Na], [K], [Cl], TCO_2, anion gap, calcium, glucose, creatinine and hemoglobin) and CG4+ cartridges (i.e., pH value, CO_2, HCO_3, O_2, base excess). Creatine kinase was measured on the fully automated UniCel DxC 800 Synchron Clinical System and cortisol on the fully automated UniCel DxI 800 Immunoassay System according to the manufacturer's instruction (both Beckman Coulter international, Nyon, Switzerland). Urine samples (i.e., urine specific gravity, urine pH value, urine glucose, urine nitrite, and urine protein) were analyzed using the Combur Test (Roche, Basel, Switzerland).

Core body temperature was continuously measured using the thermoelectric probes Endotherm (EndoTherm GmbH). The Endotherm probes were programmed to take 1 measurement every 30 seconds. The probes were applied 2:45 h:min before the start of the first swim. The probe was inserted in the rectum using a protective container provided by the manufacturer. Skin temperatures of his belly and his back were measured before a start and after getting out of the lake using an LCD hand-operated thermometer DT-300 (Voltcraft), with a temperature accuracy of 0.1° C. The temperatures were measured 3 times and the mean of the 3 measurements was analyzed further.

Statistical Analyses

All statistical analyses were performed using statistical software IBM SPSS v.20.0 (SPSS, Chicago, IL, USA) and GraphPad Prism 5 (GraphPad Software, La Jolla, CA, USA). Data were examined for normality using Shapiro-Wilk's test and visual inspection of normal Q-Q plots; because they were normally distributed, parametric statistics were applied. Descriptive statistics (mean and *SD* of the mean) were used for all data presentations. A repeated-measures 1-way analysis of variance with post hoc Bonferroni test examined pre- to postswim differences in all variances. The effect size of potential differences was examined by eta square (η^2), classified as trivial ($\eta^2 < 0.01$), small ($0.01 \leq \eta^2 < 0.06$), medium ($0.06 \leq \eta^2 < 0.14$), and large ($\eta^2 \geq 0.14$) (3). Pre- to postswim changes in all variables were calculated as percentage (i.e., 100 × [post swim value-pre swim value]/pre swim value). Pearson correlation coefficient *r* examined the relationship among changes in all variables. The magnitude of the correlation was interpreted according to the following criteria: $r \leq 0.10$, trivial; $0.10 < r \leq 0.30$, small; $0.30 < r \leq 0.50$, moderate; $0.50 < r \leq 0.70$, large; $0.70 < r \leq 0.90$, very large; and $r > 0.90$, almost perfect (15). Statistical significance was set at alpha = 0.05.

Results

The swimmer had 106.7 kg body mass, 27.5% body fat, 54.6% body water, 16 kg visceral fat mass, 3.8 kg bone mass, and 63.8 kg lean body mass before the first "Ice Mile" after the measurements of the bioelectrical impedance analysis.

The swimmer started the first "Ice Mile" on March 3, 2017, at 08:00 PM. The second "Ice Mile" started on March 4, 2017, at 09:30 AM, the third "Ice Mile" at 01:00 PM, and the fourth at 05:30 PM. The fifth "Ice Mile" started then on March 5, 2017, at 09:00 AM and the sixth one at 12:00 PM on the same day. Environmental conditions and core body temperatures are displayed in Table 1. Regarding the water temperatures, only 3 of the 6 miles were official Ice Miles fulfilling the strict criteria of the IISA.

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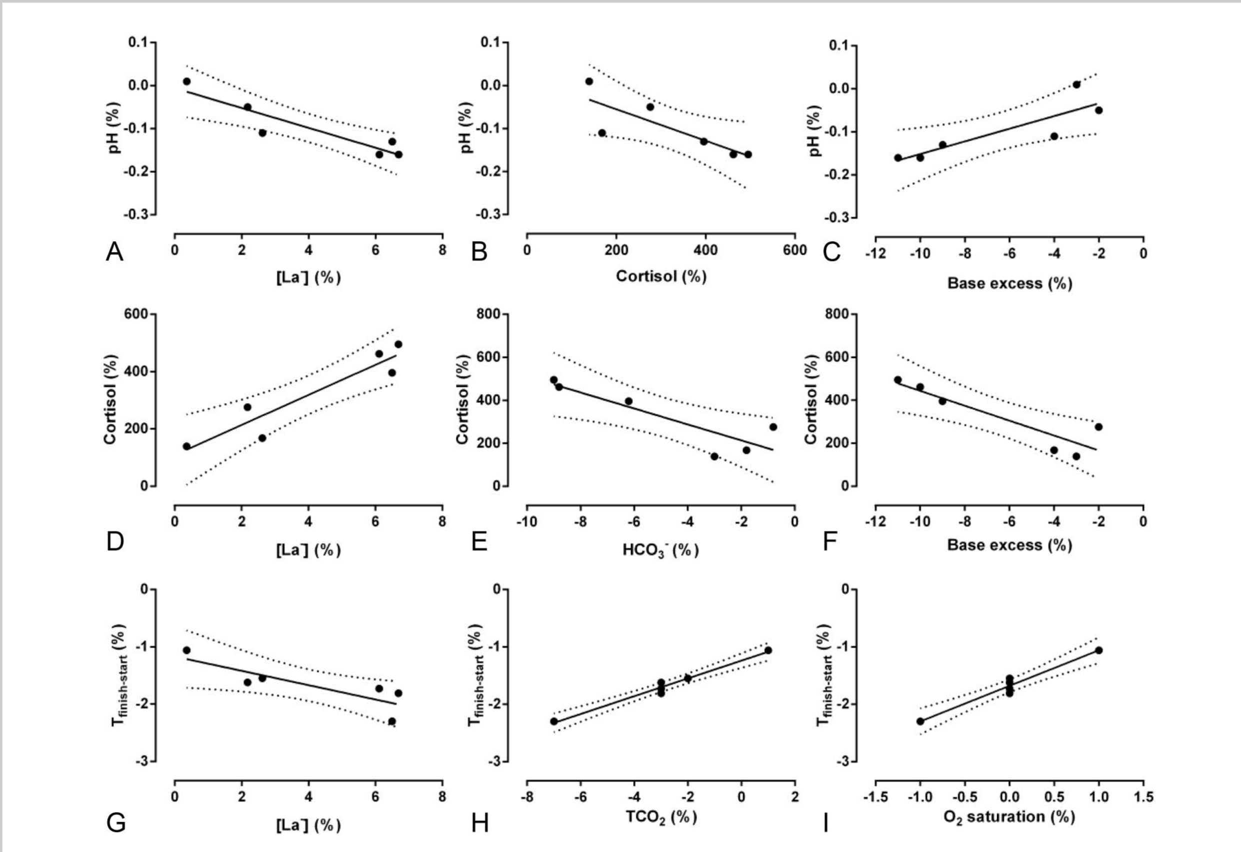

Figure 2. A–C) Changes in pH compared with lactate concentration, cortisol, and base excess; (D–F) changes in cortisol compared with lactate concentration, bicarbonate, and base excess; (G–I) changes in the difference of body temperature from the start to the finish compared with lactate concentration, total carbon dioxide, and oxygen saturation; dashed lines represent 95% confidence intervals.

Differences between pre- and postswim results are presented in Table 2. Base excess, pH, HCO_3^-, calculated total CO_2, TCO_2 and glucose decreased, whereas lactate, chloride and creatine kinase increased ($p < 0.05$, $\eta^2 > 0.495$). The largest magnitude of difference was observed in creatine kinase, cortisol, lactate, and base excess.

Skin body temperature dropped from pre- to postswim measures, being 29.95 (3.15)° C (mean [*SD*]) to 6.0 (1.98)° C and 28.63 (3.24)° C to 9.47 (1.92)° C for the belly and back, respectively. At the start to the Ice Miles, core body temperature was 37.89 (0.21)° C and increased within 4.0 (2.2) minutes after the start of an "Ice Mile" to 37.97 (0.18)° C as maximal temperature (Tmax). At the finish of the Ice Miles, core body temperature was 36.21 (0.42)° C (Table 1). Minimal postswim temperature (Tmin) was 35.39 (0.63)° C at 28.0 (6.7) minutes after finish of the Ice Miles (Figure 1).

We observed an association between cortisol change (%) and increased metabolic acidosis (i.e., decreased pH and base excess and increased lactate concentration; Figures 2A–2F). The change in pH was significantly and negatively associated with the change in lactate concentration ($r = -0.925$, $p = 0.008$), and the change in cortisol ($r = -0.825$, $p = 0.043$) and significantly and positively associated with the change in base excess ($r = 0.853$, $p = 0.031$). The change in cortisol was significantly and positively associated with the change in lactate concentration ($r = 0.936$, $p = 0.006$) and significantly and negatively with the change in HCO_3^- ($r = -0.876$, $p = 0.022$) and the change in base excess ($r = -0.902$, $p = 0.014$).

Moreover, body temperature change (%) showed a positive association with TCO_2 ($r = 0.987$, $p = 0.0001$) and O_2 saturation ($r = 0.975$, $p = 0.001$) and a negative association with lactate concentration ($r = -0.836$, $p = 0.037$; Figures 2G–2I).

Discussion

This is the first scientific report that investigated the physiological responses to swimming several Ice Miles in a row. The main results were that after each one of the 6 Ice Miles, the athlete had an increased metabolic acidosis and an increase in blood glucose and creatine kinase levels. Furthermore, the change in cortisol was positively associated with increased acidosis, and changes in core body temperature (i.e., difference between the start and finish) were negatively associated with metabolic acidosis, i.e., the larger the change in temperature, the lower the pH.

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With regards to hematological values, base excess and HCO_3^- decreased, whereas lactate concentration increased postswim indicating a metabolic acidosis, which the swimmer compensated with a respiratory response as shown by a decrease in TCO_2. An explanation of the increase in blood glucose levels preswim might be food intake (i.e., carbohydrate-rich sandwiches). Blood glucose level was, however, increased after the swim and 30 minutes after the swim above preswim levels. This increase was most probably due to the high level of physical stress (30).

The increase in cortisol indicates the enormous stress for his body (12) and is in agreement with a previous study of a 32-km swimming event (7). The length of an open-water swimming event might be responsible for the degree of the increase, although it is not clear whether this increase results from the low water temperature or the exercise in the present case study. During a 78.1-km solo ultra-endurance open-water swimming event, cortisol showed a 23-fold increase (4). An increase in cortisol in swimmers has been shown for ultra-distance swimmers; however, cortisol showed no changes in competitive elite pool swimmers during training (6,27). For pool swimmers, the intensity in swimming must be high enough in training to induce an increase in cortisol. In male swimmers performing an interval training session consisting of 15 × 100-m freestyle efforts at 95% of their maximal exercise intensity, cortisol level increased significantly (17).

In addition to cortisol, creatine kinase increased too. The increased creatine kinase suggests skeletal muscle damages due to shivering after a swim (2). For swimmers, the intensity seems of importance to increase creatine kinase. It has been observed in a previous study that when highly trained swimmers completed a maximum work capacity tethered swim and a 1-hour continuous tethered swim at approximately 70% $\dot{V}O_2max$, no significant increase in creatine kinase could be found, suggesting that exercise intensity was not sufficient to impose sufficient degrees of trauma producing muscular stress (35). Nevertheless, the changes in creatine kinase should be attributed to the increased exercise-induced physiological stress in the present case study.

Surprisingly, the core body temperature increased to 38° C at 4 minutes after the start of the swim, showing the effect known as "anticipatory thermogenesis" (25). The increase in core body temperature might be due to peripheral vasoconstriction and the exercise-induced increase in metabolic heat production (24). An increase in core body temperature in the first minutes in the cold water might be due to preswim heating. However, the swimmer followed no specific procedure to increase his core body temperature before a start. A further potential explanation could be the intense muscular contractions in the first minutes to adapt to the cold. The phenomenon of "anticipatory thermogenesis" has been defined by Noakes et al. (25) when investigating the ice swimmer Lewis William Gordon Pugh. This swimmer was able to increase his core body temperature before a start of an ice swim. "As soon as I enter cold water my body shunts all my warm blood to my core to protect my vital organs. It then generates incredible heat," Pugh said. "Before I even enter the water, I am able to elevate my core body temperature by as much as 1.4° C." This phenomenon has, to our knowledge, not been noted in any other human (www.telegraph.co.uk/news/worldnews/1557610/North-Pole-swimmers-unique-body-heat-trick.html).

The swimmer suffered an afterdrop postswim resulting in hypothermia, defined as core body temperature <36.0° C (9). It should be highlighted that hypothermia is the most prevalent medical risk in open-water swimming (23). However, the subject's high body mass index and long experience in cold-water swimming could explain the maintenance of his core body temperature (20). Moreover, a positive correlation between rectal temperature and body fat has been observed at the end of a 32-km swimming event (7).

The change in pH during an "Ice Mile" has an almost perfect inverse correlation with the change in lactate, indicating that lactate accumulation is the main reason in causing metabolic acidosis. Lactate plays a role as a signaling molecule, fuel, and a gluconeogenic substrate (14). In addition, the change in pH also correlated very largely with the increase in cortisol level, indicating that the intense exercise causes a considerable metabolic stress. The positive correlation between changes in pH and base excess shows the metabolic compensation mechanism. The observed association between changes in cortisol and lactate could be explained by the increase in cortisol level during high-intensity exercise (12). Furthermore, an explanation of the decreased bicarbonate level might be the respiratory compensation of the metabolic acidosis, and the decreasing base excess is due to the metabolic compensation mechanisms.

The changes in core body temperature from the start to the finish were associated with lactate concentration, total carbon dioxide, and oxygen saturation. A larger difference in temperature negatively correlates with lactate levels, indicating more effort and anaerobic exercise and probably shorter swim duration. That is bound to a higher decrease in TCO_2 because of respiratory compensation of the metabolic acidosis.

We should be aware that prolonged exercise with and without thermal stress leads to exercise-induced increases in core body temperature, heart rate, cortisol, lactate, and creatine kinase as it has been shown in different studies with different subjects in different sports disciplines (5,10,13,39). The significance of the observed changes in the present swimmer should be verified in a comparison of the same distances and swim times in water colder than 5° C and in water at moderate temperatures (e.g., 20–25° C) to quantify the thermal stress of the cold water.

It should be highlighted that the participant in the present case study was an experienced swimmer in cold water. Therefore, the results should be generalized with caution to swimmers with less experience because swimming in cold

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water in unaccustomed persons may have detrimental effects, whereas adaptive physiologic mechanisms increase tolerance to cold water in experienced swimmers(21). Further limitations may be that rectal temperatures are responding slowly and may give an artefactual afterdrop. The accuracy of blood samples from an ear immediately after swimming in cold water might be limited. On the other hand, strength of this study was its novelty as previous studies on swimming in cold used shorter exercise distances such as 150 m (22) or warmer water temperatures (40). Further studies should consider the circadian rhythm of cortisol excretion as this hormone undergoes a circadian rhythm, which could have influenced the preswim values. Furthermore, cold-induced diuresis and changes in blood volume due to diuresis might be measured. Future studies should use the present findings as reference and recruit larger samples.

Practical Applications

Although exercise under extreme conditions is a major field of exercise physiology enhancing theoretical knowledge for exercise physiologists and practical applications for strength and conditioning coaches, surprisingly a few studies have been conducted on prolonged swimming in cold water so far (18–20,34). On the other hand, a large body of literature has examined acute responses to short-term exposure to cold water in the context of postexercise recovery or preexercise strategy to enhance performance (1,8,11,16,18,28,31,33,36). Swimming 1 mile in cold water decreases both base excess and HCO_3^- and increases lactate concentration. These changes led to a metabolic acidosis, which the swimmer tried to compensate with a respiratory response as shown by a decrease in TCO_2. The decrease in pH correlated significantly and negatively with the increase in cortisol level, indicating that this intense exercise causes a metabolic stress. The increase in creatine kinase suggests skeletal muscle damages due to shivering after an "Ice Mile." Most probably neuromuscular cooling and swim failure rather than general hypothermia are more hazardous for ice swimming. Considering the increasing popularity of ice swimming, the findings have practical value for swimmers and practitioners (strength and conditioning coaches, exercise physiologists, and physicians) working with them as our results provide a detailed description of acute physiological responses to repeated swimming in cold conditions. In addition, the knowledge for the changes in temperature and physiological parameters during the swim and postexercise can be generalized in other settings of open-water swimming under similar environmental conditions and exercise characteristics. These findings are of importance for athletes and strength and conditioning coaches for National Championships and World Championships in Ice Swimming following the IISA rules.

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